A Geometric Descriptor for Cell-Division Detection

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Abstract

We describe a method for cell-division detection based on a geometric-driven descriptor that can be represented as a 5-layers processing network, based mainly on wavelet filtering and a test for mirror symmetry between pairs of pixels. After the centroids of the descriptors are computed for a sequence of frames, the two-steps piecewise constant function that best fits the sequence of centroids determines the frame where the division occurs.

1 Introduction

Cell-division events are of great relevance in biology research. In the particular case of human embryos, for instance, cell-division times have been shown to be correlated with viability for re-implantation [4, 5]. In the more general case of mammal embryos, division events are critical when modeling cell tracking in order to build a cell lineage tree [2].

In this work we focus on the problem of detecting when a cell divides. In that direction, we devise a descriptor that serves two purposes. First, it can be used for information visualization, as it allows spotting the point in a video sequence where a cell-division occurs (as depicted in the third row of Figure 2). This provides a summary of the video that speeds up some manual annotation tasks. Second, we use the descriptor as the basis for an automatic division detection algorithm. The algorithm computes the centroids of the descriptors for a sequence of frames, and then finds the two-steps piecewise constant function that best fits the data. The "step" point of such function determines the frame of cell division.

The descriptor is a 5-layers processing network (see Figure 1) based on a bank of morlet-wavelet filters (as in [1]), and a test for mirror symmetry between pairs of pixels (as in [3]).

2 Problem Statement

The input is sequence of frames from time-lapse microscopy of early-mouse embryos. We look at a segment of video containing 150 frames, where the embryo undergoes the first cell division, going from one to two cells. We want to devise a method that represents relevant changes in information content throughout the frames, that is, an "invariant" for the number of cells. Besides, we look for a robust method for automatically detecting cell division events.

3 Proposed Solution

The proposed descriptor is a histogram of radii. The radii are computed for pairs of points whose tangents are mirror symmetric (as defined in [3]). We notice that a mirror symmetric pair of points uniquely defines a circle. To compute the tangents we use a bank of morlet-wavelet filters (as defined in [1]), with fixed scale (determined empirically) and varying orientation. This descriptor can be seen as a 5-layers network, as depicted in Figure 1.

Examples for the sequence of descriptor are shown in the third row of Figure 2. Next, we compute the centroids of the histograms (second row of Figure 2). The sequence of centroids visibly reveal a shift in value in the frame that correspond to cell division. To compute this frame, we look for the best two-steps piecewise constant function that fits the centroids curve. The best piecewise function is computed as follows.

Let n be the number of frames (in our case 150), $\{f(j), j = 1, ..., n\}$ the sequence of centroids, and $\{c(j), j = 1, ..., n\}$ a cost function (to be computed). For each $j = 2, ..., n$, split the set f in two segments, $f_j^- = \{f(1), ..., f(j-1)\}$ and $f_j^+ = \{f(j), ..., f(n)\}$, and define $c(j) = variance(f^-) + variance(f^+)$. For completeness, define $c(1) = c(2)$. Let $\hat{j} = \arg\min c(j)$. The two-steps piecewise constant function g that best fits f is defined as $g(j) = mean(f_{\hat{j}}^-)$ for $j = 1, ..., \hat{j} - 1$, and $g(j) = mean(f_{\hat{j}}^+)$ for $j = \hat{j}, ..., n$. Figure 2, top, shows some examples of cost functions.

In a test with 93 examples, this method detected the frame of division within 1 frame of the true value in 54% of the cases, and within 5 frames of the true value in 80% of the cases. In comparison, the performance obtained by computing the maximum of the sum of the absolute pixel-by-pixel differences between consecutive frames (as described in [4]) is of 34% and 40%, respectively.

4 Future Work

We are currently working on extending the described method to detect later cell divisions, mainly the approximate times where the number of cells goes from 2 to 4 and form 4 to 8. This can be achieved, for instance, by sliding a window of fixed size through the curve of centroids and computing the local linear regression that best fits the data. The curve of estimated slopes thus produced will have local plateau at the locations of cell division. We obtained satisfactory preliminary results with this method. Later, this technique should be used in conjunction with a cell tracking method in order to build the lineage tree up to the 8-cell stage.

Fitting a piecewise constant function on time series, and correspondent event detection, have applications in other areas as well. In audio analysis, for instance, a descriptor of chords will generally show a piecewise-constant behavior. Likewise for a pitch detector applied to certain musical instruments. The output of fitting would allow for, among other things, key and scale recognition.

References

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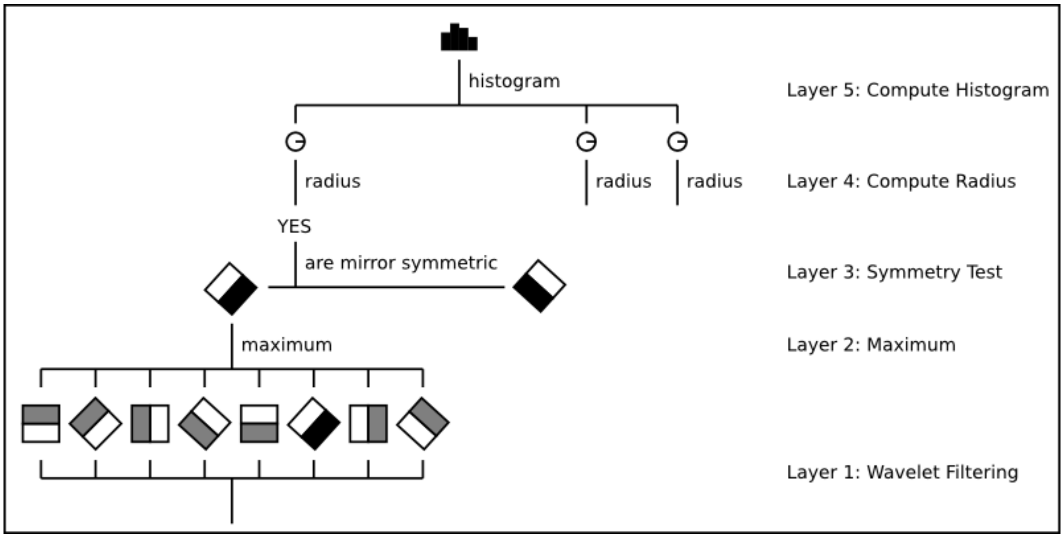

Figure 1: The descriptor used for cell-division detection can be represented as a 5-layers processing network. First, each pixel neighborhood is multiplied by wavelet filters of fixed sizes and variable orientations. Second, the maximum of the output values gives the orientation of the possible edge passing through the pixel (if the maximum value passes some threshold). Next, each pairs of pixels is tested for mirror symmetry. If they pass, the corresponding radius of the circle they define is computed. The histogram of such radii for the whole image defines the descriptor.

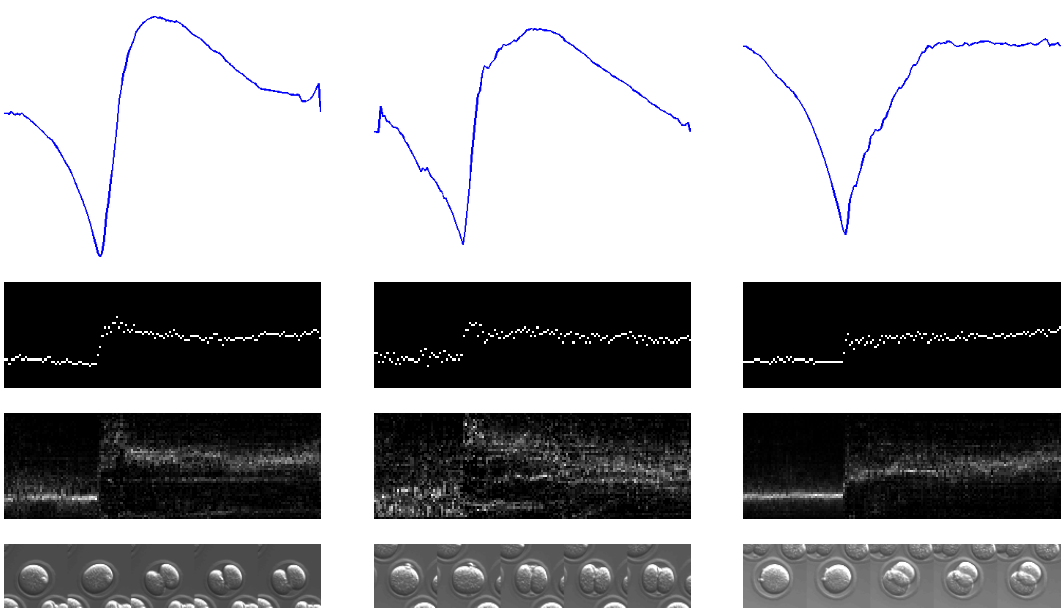

Figure 2: Some steps for computing the point of cell division are shown here for three examples. The images in the third row show the radii histogram. The second row plots the centroids of the columns for the images at the third row. The first row of images show the cost functions whose minima determine the frames of cell division. The computation of the cost function is detailed in the main text. Images on the last row are formed by frames around the detected division point.